1991 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

LOW FLOW VORTEX SHEDDING FLOW METER FOR HYPERGOLICS/ALL MEDIA

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DATE:	August 2, 1991
CONTRACT NUMBER:	University of Central Florida NASA-NGT-60002 Supplement: 6

SUMMARY

Current turbine flow meters have been used to measure the loading of hypergols into the Space Shuttle Orbiter. Because of the problems associated with the refurbishment of these meters after each launch, NASA has considered the development of a vortex shedding flow meter which would have no internal moving parts. The objective of the current project was to develop a family of vortex shedding flow meters with outside diameters varying from 1/2" to 2" for a low flow environment.

To test the meters with the flow of water and Freon 113 which has fluid properties similar to hypergols, two flow test loops were designed and built. One loop was for the 1/2" model using Freon 113 as operating fluid. Another loop consisted of a pump system was designed for the larger models of 3/4", 1", 1.5" and 2" O.D. using water as operating fluid. A family of flow meter models consisted of 13 different configurations were designed and fabricated. Test runs were conducted successfully on the 1/2" models with Freon 113 and the others with water.

Results showed that the linearity between the frequency of the vortices and the flow rate of Freon 113 and water for all flow meters with a rectangular shedder bar was very close to that of the turbine type. It is concluded that the vortex shedding flow meter is a possible replacement for the turbine flow meter being used on the space shuttle.

ACKNOWLEDGEMENTS

I would like to thank all members of the **Transducers Section** for their help during my tenure at Kennedy Space Center. I am grateful to **Bob Howard** for his encourage words which brought me to this interesting project and his strong support toward my research endeavour. Special thanks should be extended to **Bill Larson** for his support and assistance that make my work less painful. I also would like to thank **Jerry Mason, Jim Hillis, Drew Schmidt** and **Steve Stout** for their assistance, without their help I would not be able to complete successfully this experimental study. Finally, I would like to thank **Dr. E. Ramon Hosler** and **Dr. Mark A. Beymer,** Directors of the NASA/ASEE Summer Faculty Fellowship Program, and **Mrs. Kari L. Stiles**, Administrative Assistant, for their assistance and hospitality which make my days at KSC very educational and enjoyable.

Abstract

The purpose of this summer project was to develop a family of vortex shedding flow meters for flow measurements of hypergols that requires a long term operation without removal from system lines. A family of vortex shedding flow meters without moving parts was designed and fabricated. The test loops to evaluate the meters for water flow as well as Freon -113 flow which simulates the hypergolic fluids, have been modified and constructed to utilize a pump system which has an output capacity of 200 gpm.

Test runs were conducted on the small 1/2" model with Freon 113 and on the larger size models with water. Results showed that the linearity between the frequency of the vortices and the flow rate of the fluids was very close to that of the turbine flow meter. It is suggested that the vortex shedding flow meter is a possible replacement for the existing turbine type.

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I. INTRODUCTION

1.1 STATEMENT OF PROJECT NEEDS.

During the loading of hypergolic fuels and oxidizers, flow meters are used to measure the amount of fluid. The current method of metering these fluids involves turbine type meters and shuttle-ball type vortex shedding meters. One of the problems that occurs with these meters is that after each launch the meters have to be taken apart and refurbished then recalibrated. The reason for this process is that there are moving parts of the meters in contact with the flowing fluid. The bushings and bearings of these meters are susceptible to wear, especially during the purge phase of fuel loading process when severe over-speeds of the rotor occur due to gas flow through the lines. The process of refurbishment of the meters is costly due to the techniques required to handle the very toxic hypergols. It is estimated that a saving of about $1000 per flow meter per launch can be made if the meters do not require this maintenance. There are about 6000 flow meters of all sorts being used.

1.2 OBJECTIVE OF THE PROJECT.

The objective of this project is to develop a family of vortex shedding flow meter for applications that require long term operation without removal from system lines. This family of vortex shedding flow meters would have no moving parts. The linearity between the frequency of the vortices and the flow rate of the fluid would be as close as that of the turbine type. The flow meters would be installed permanently after the initial calibration and only the signal conditioner would be removed for calibration. This procedure would not affect the total calibration accuracy of the meters.

II. VORTEX SHEDDING FLOW METER

2.1 BACKGROUND OF VORTEX SHEDDING PHENOMENA.

The phenomenon of vortices being shed from a surface in a flowing fluid is not new, and the application of the vortex shedding to the measurement of flow rate is well established. For an uniform flow past a circular past a circular cylinder, vortices are formed at the two separation points and shed off regularly in an alternating fashion, as shown in figure 2.0. These vortices move downstream in a regular pattern.

The vortices move downstream with a velocity which is less than the mainstream velocity . The alternating shedding of vortices from the separation points on the surface of a circular cylinder produces transverse forces on the cylinder and causes the cylinder to oscillate. Such effects were first studied in the laboratory about 1878 by Strouhal, who showed that the vibrations would cause the pressure pulses to transverse to the fluid. He also showed that the frequency f of the vibration was related to the AIR speed U and the cylinder diameter d by the approximate equation:

$$f = U/(6*d) \qquad (1)$$

The vortex shedding flow meter works on the principle that the mass flow rate of the fluid is proportional to the frequency of the vortex shedding behind a bluff body as shown in Figure 2.1.

The proportionality constant or the relationship between the vortex shedding frequency and velocity of the uniform flow is called the **Strouhal number** which is related to the vortex shedding frequency in the following equation:

$$f = St*U/d*(1 - 20/Re) \qquad (2)$$

where:

f	Vortex shedding frequency, Hz
St	Strouhal number
U	Fluid flow velocity, ft/sec
d	Characteristic dimension of bluff body, ft
Re	Reynolds number of pipe flow

2.2 DESIGN OF THE PROTOTYPES

Figure 2.2 shows the design for a family of vortex shedding flow meter with a shedder bar. Table 2.1 shows all dimensions in inches. The geometry of the shedder bar may determines the characteristic of the frequency of vortices. Three shapes for the shedder bar were selected for this study. They are circular, rectangular, and reversed wedge as shown in following figure 2.3. Table 2.2 shows the dimensions of the flow meter diameters and the shedder bar.

III. EXPERIMENTAL STUDY

3.1 INTRODUCTION

The test runs in this study were conducted on the family of vortex shedding flow meters using Freon 113 and water as operating fluids. A Labview software was used to acquire and analyse the pressure signals. The Least Squared Estimation method was used to curvefit the data points and to determine the linearity of the flow rate and the vortex shedding frequency.

3.2 FLOW BENCH DESIGN

Two flow benches were designed and built for the testing of the flow meters. Figures 3.1 and 3.2 show the flow loop for the study of the 1/2" models using Freon as an operating fluid. Two 50-gallon dewars were used as containers for the Freon fluid. Dewar #1 was located inside the laboratory and was placed on a load platform used to measure the mass flow rate of Freon 113. Dewar #2 was located outside of the laboratory window and was connected to the flow loop through the window. By proper adjustments of the valve system, Freon 113 could flow through the loop from either dewar. High pressurized air was used to vent Freon from one dewar through the test section into the other dewar. The quantities measured in the loop include the output signals from the turbine flow meter used as a reference, from the vortex shedding flow meter under test, from the pressure transducer and the thermocouple in the test loop, and from the load cell transducers installed under dewar #1. The vortex flow meter output signals were detected by a Kistler transducer (model 206). The Kistler transducer was a piezoelectric type of device and came with a Kistler signal coupler (model 5116) which could produce an AC coupled millivolts output proportional to the pressure fluctuations. The Labview data acquisition was used to analyze the output signals. The frequency of the vortices as well as the mass flow rate of the fluids were also obtained. Figure 3.3 and 3.4 show the flow bench designed for the larger size models. The flow bench consists of two 250-gallon tanks acting as a source and a sink, a pumping system, and a test section. Similar to the previous flow loop, the vortex flow meter output signals were also detected by a Kistler transducer (model 206) and amplified by by a Kistler signal coupler (model 5116). The Labview software was also used for the test runs with this flow bench.

3.3 TEST RUNS AND DATA COLLECTIONS

The goal for this summer project was to study experimentally a family of vortex shedding flow meter using the turbine type as a reference. The pump speed or the valve system was adjusted to vary the flow rate. Steady flow was indicated by a steady output reading from the calibrated turbine meter in series with the vortex meter. The turbine meter output consists of a voltage from the signal conditioner which is linearly proportional to the flow rate.

The output from the vortex shedding flow meter was analyzed using the Labview data acquisition software. The output signal from the Kistler transducer was clearly picked up on the Labview oscilloscope and the primary frequency results were obtained easily from the FFT (Fast Fourier Transform) operation. The measurement of pressure, temperature, and turbine flow rate were also conducted simultaneously. Figure 3.5 shows a sample output consisted of a raw signal waveform, a low frequency filtered waveform, FFT calculation, and related information.

3.4 RESULTS AND EVALUATIONS

Figures 3.7 to 3.11 represent the relationship between the frequency of the vortices and the flow rate of the fluid for all the flow meters designed. The goal for this study is to determine the linearity of the flow meter frequency curves. Figures 3.7a to 3.11a show the straight line equations for the test data obtained on the models with a rectangular shedder bar. Figures 3.7b to 3.11b and Figures 3.7c to 3.9c show the same results for the cylindrical and reversed wedge bars respectively.

It is noted that the rectangular and reversed wedge shedder bars produced a clear separation flow which in term provided a good waveform for the pressure pulses. The frequency was also easier to be calculated by hands or with the FFT operation. To determine the validity of the linearity for the flow rate vs frequency curves, the Multiple Correlation Coefficient Squared named "R^2" was used. For a straight line curve R^2 was calculated to be 100%. Figures 3.7 to 3.11 showed that the MCCS or R^2 for the rectangular and reversed wedge bars was about 99.2% and for the cylindrical shedder bar the MCCS was about 95%.

IV. CONCLUSION AND RECOMMENDATION

Test results on the designed family of vortex shedding flow meters suggested that the vortex shedding flow meter is a **possible replacement** for the turbine flow meter which has been used to measure the loading of hypergols into the space shuttle.

The rectangular and reversed wedge shedder bars generate stable vortices; therefore, the frequency count is easily obtained. From the manufacturing point of view the rectangular bar may be simpler to be fabricated.

It is suggested that a production prototype (Fig. 3.12) be developed for qualification tests and specification requirements.

Further studies can be made on the existing models such as the experimental study of a vortex shedding flow meter for gases (air, nitrogen...) and for a two-phase flow (gas + liquid, ...).

Because of the symmetrical aspect of the design, a bi-directional vortex shedding flow meter can be easily developed.

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TABLE 2.1

VORTEX SHEDDING FLOW METER DIMENSIONS IN INCHES

FLOW METER (O.D.)	1/2"	3/4"	1"	1 1/2"	2"
a	2.500	3.000	3.500	4.000	4.500
b	0.435	0.570	0.587	0.685	0.850
c	0.815	0.930	1.163	1.315	1.400
d	0.815	0.930	1.163	1.315	1.400
e	0.435	0.570	0.587	0.685	0.850
f	1.250	1.5625	2.1875	2.750	3.375
g	1.000	1.000	1.000	1.000	1.000
h	0.500	0.6563	0.8435	1.125	1.4375
i	0.447	0.398	0.328	0.281	0.205
j	0.394	0.609	0.844	1.312	1.780
k	1.000	1.3125	1.6875	2.250	2.875
l	0.4375	0.4375	0.4375	0.4375	0.4375
m	0.625	0.625	0.625	0.625	0.625
n	0.125	0.125	0.125	0.125	0.125
o	1.000	1.3125	1.6875	2.250	2.875
p	0.125	0.125	0.250	0.250	0.250
q	0.303	0.3515	0.422	0.469	0.5475
r	0.394	0.609	0.844	1.312	1.780
s	0.303	0.3515	0.422	0.469	0.5475
t	0.125	0.125	0.250	0.250	0.250
u	0.375	0.375	0.500	0.625	0.750
v	0.250	0.250	0.375	0.500	0.625

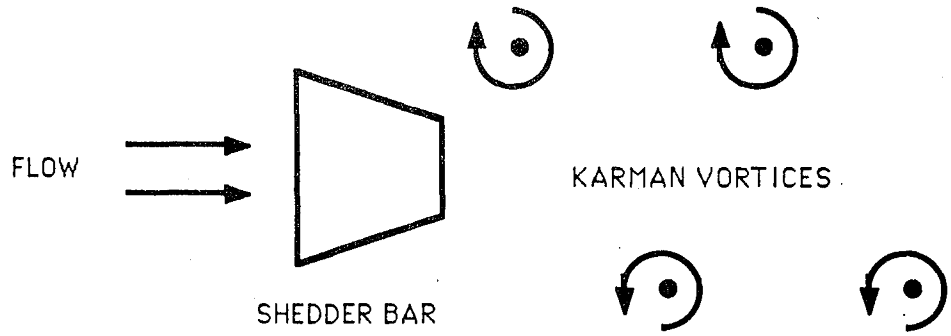

FIG. 2.0 VORTEX SHEDDING PHENOMENON

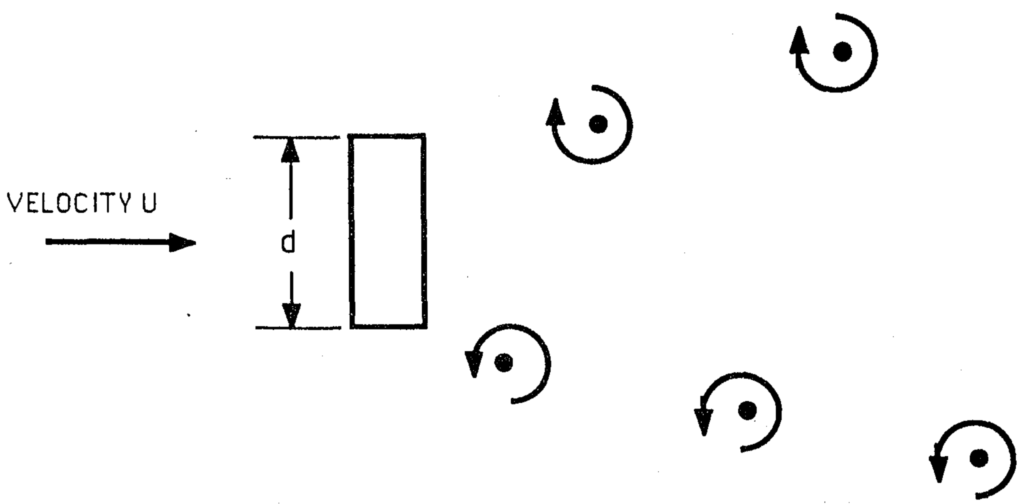

FIG. 2.1 VORTEX SHEDDING BEHIND A BLUFF BODY

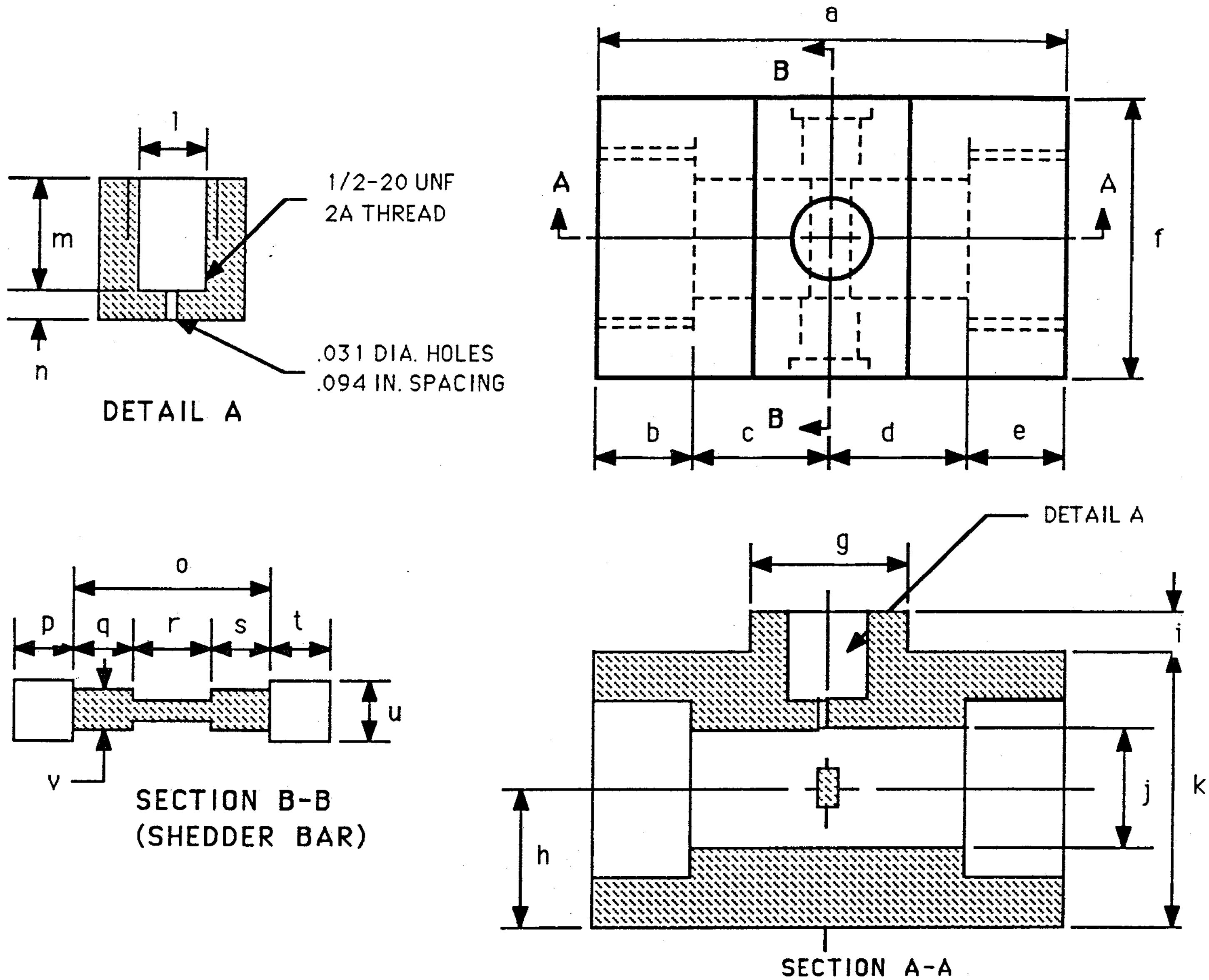

FIG. 2.2 VORTEX SHEDDING FLOWMETER PROTOTYPE

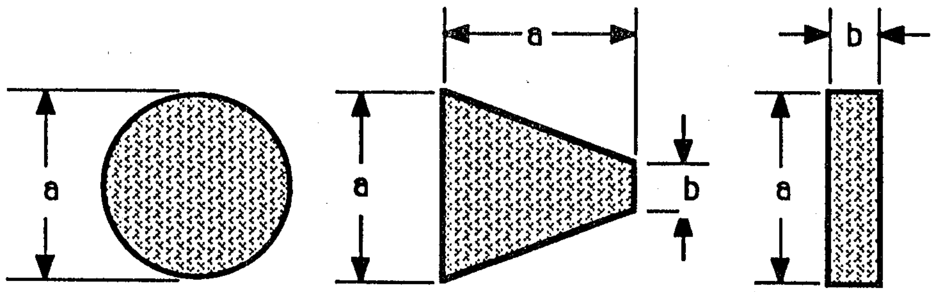

FIG. 2.3 SHEDDER BAR GEOMETRY

TABLE 2.2

SHEDDER BAR DIMENSIONS

FLOW METER (O.D)	1/2"	3/4"	1"	1 1/2"	
I.D. (in.)	.410	.609	.844	1.312	1.781
a (in.)	.110	.170	.235	.367	.500
b (in.)	.075	.115	.155	.245	.335

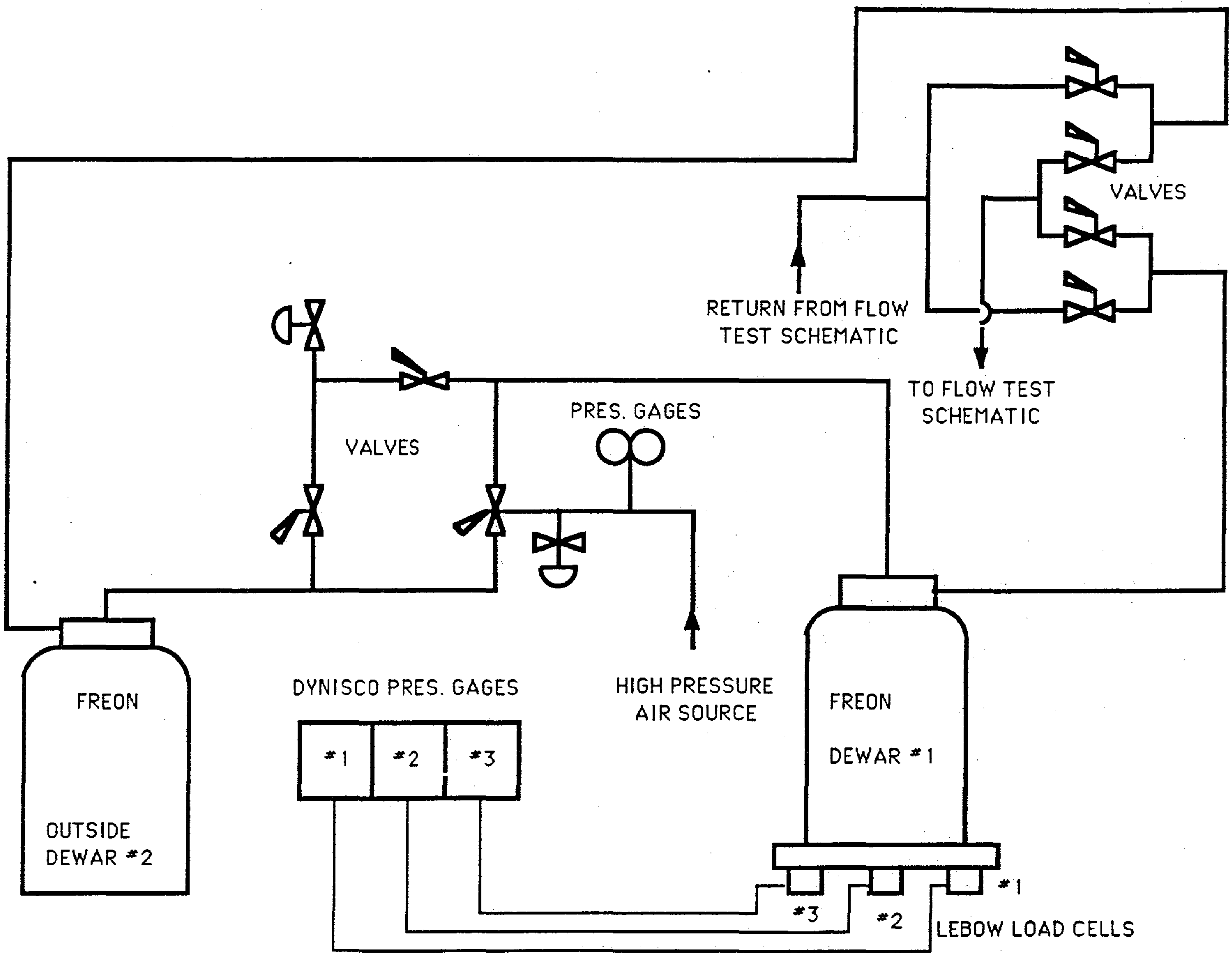

FIGURE 3.1 FLOW TANK SET UP

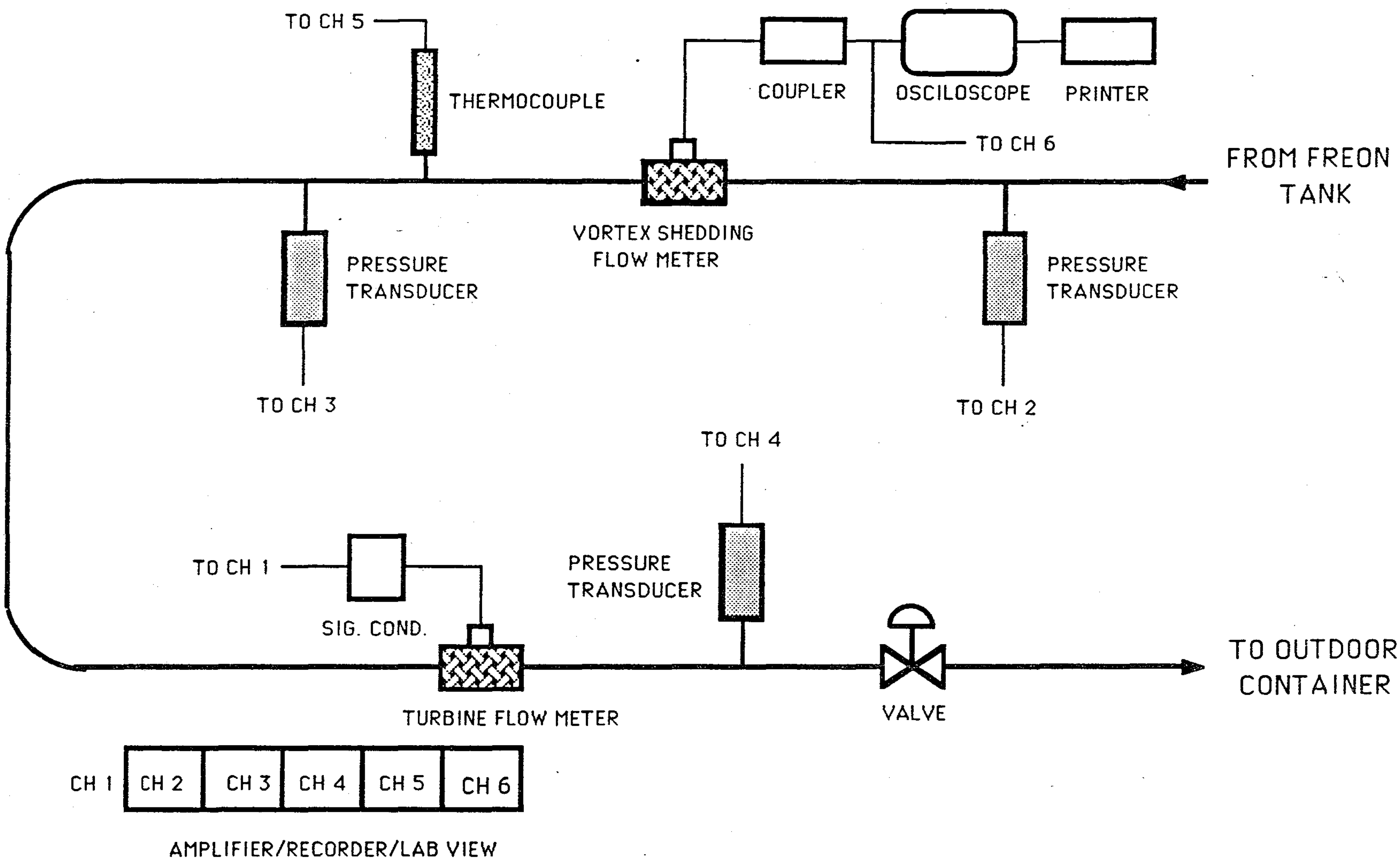

FIGURE 3.2 FLOW TEST SCHEMATIC

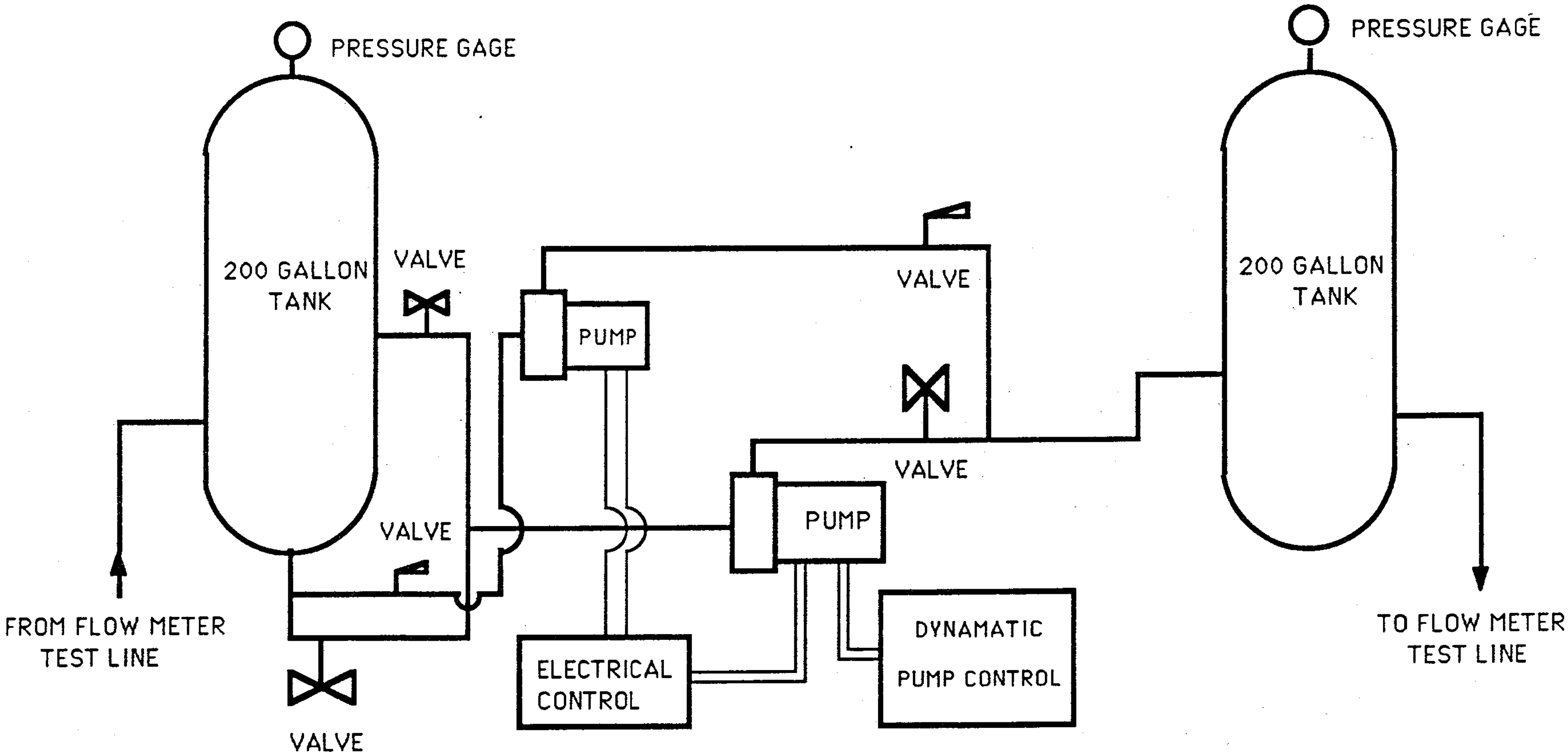

FIGURE 3.3 FLOW BENCH SCHEMATIC

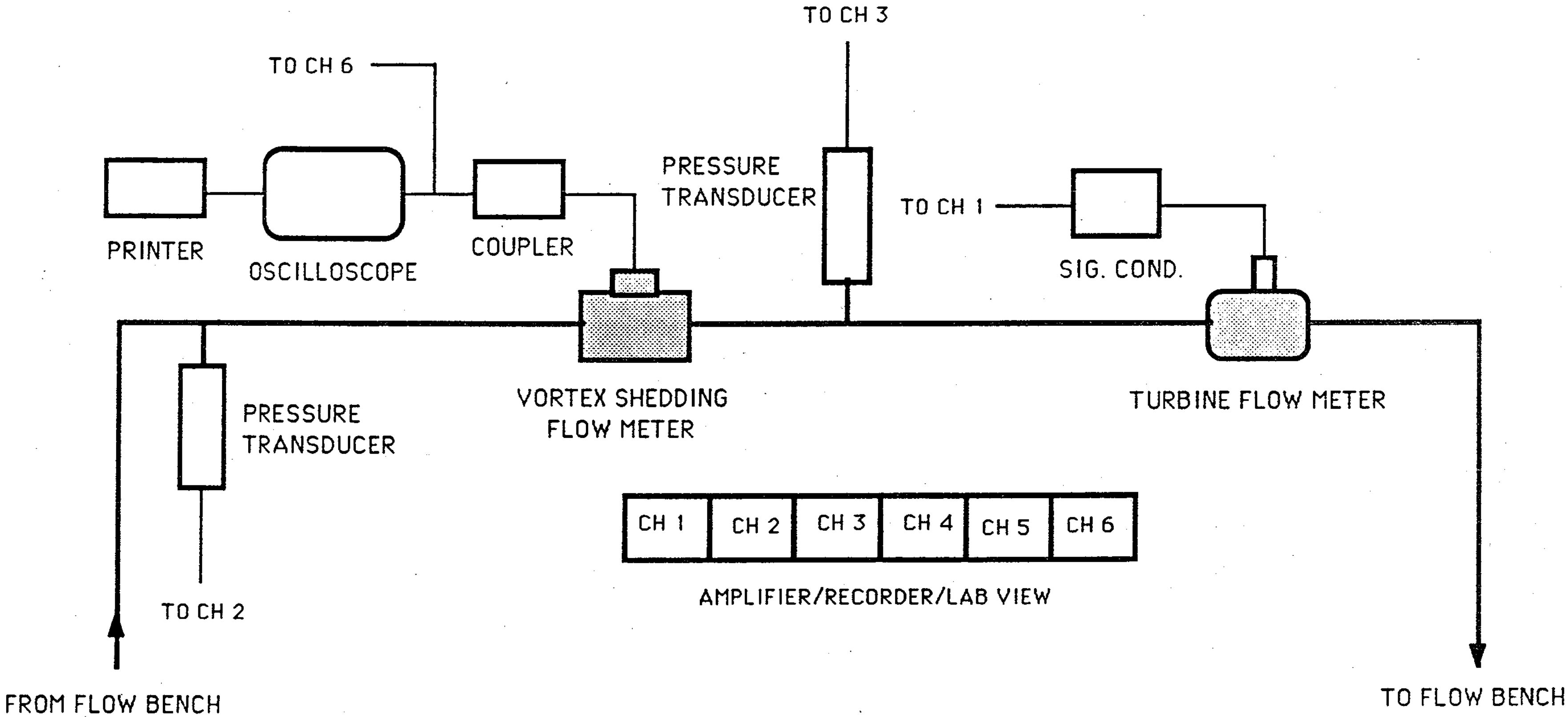

FIGURE 3.4 FLOW METER TEST LINE

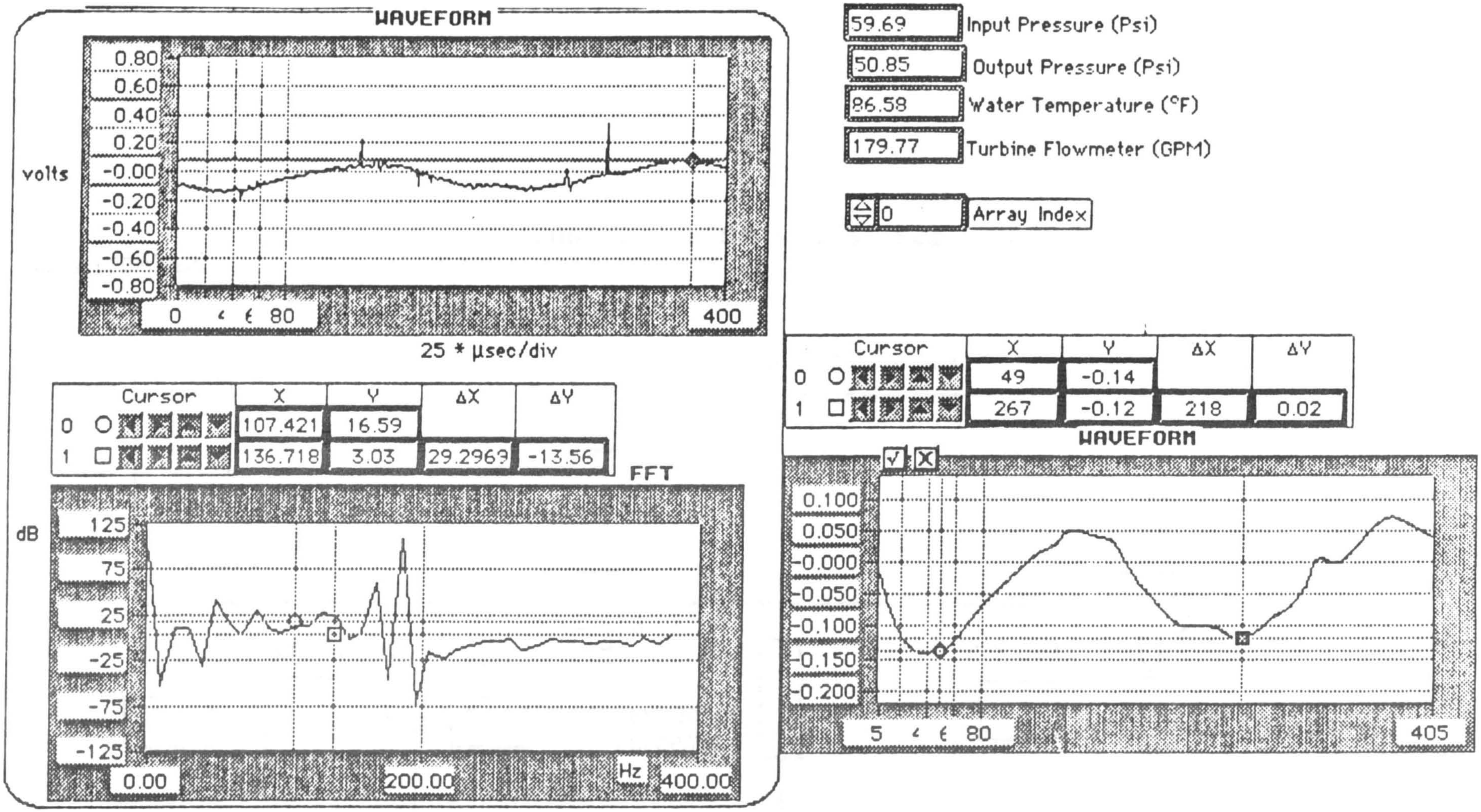

FIGURE 3.5 LABVIEW OUTPUT SAMPLE

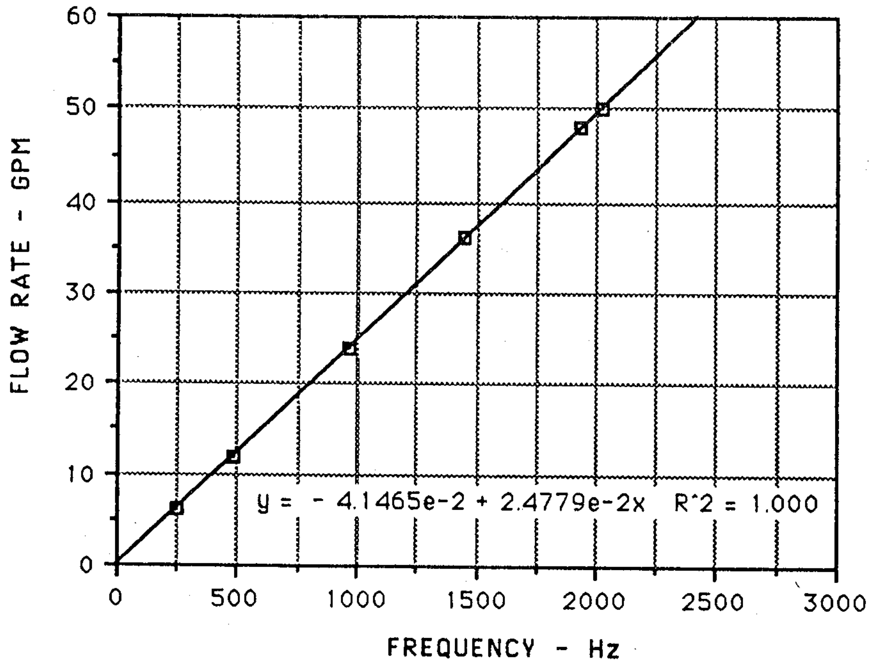

FIG. 3.6 LEAST SQUARED ESTIMATION

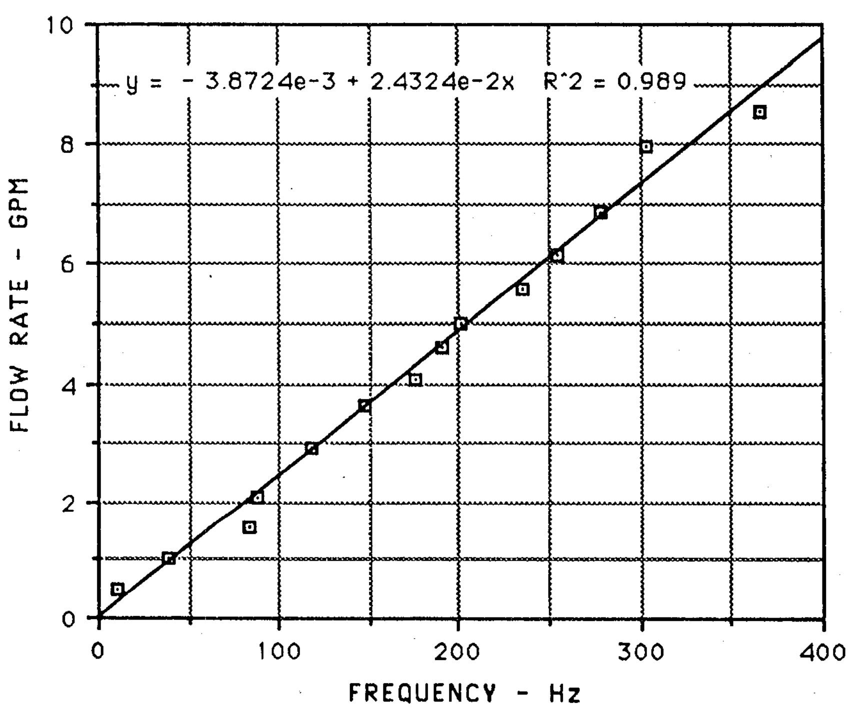

FIG. 3.7a 0.5" MODEL -RECT. BAR - FREON

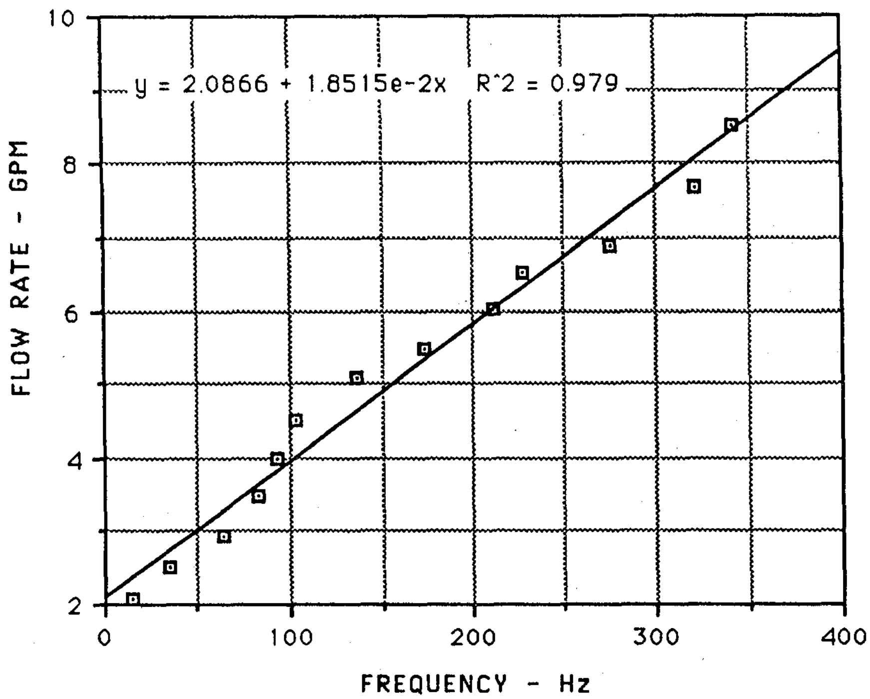

FIG. 3.7b 0.5" MODEL - CYL. BAR - FREON

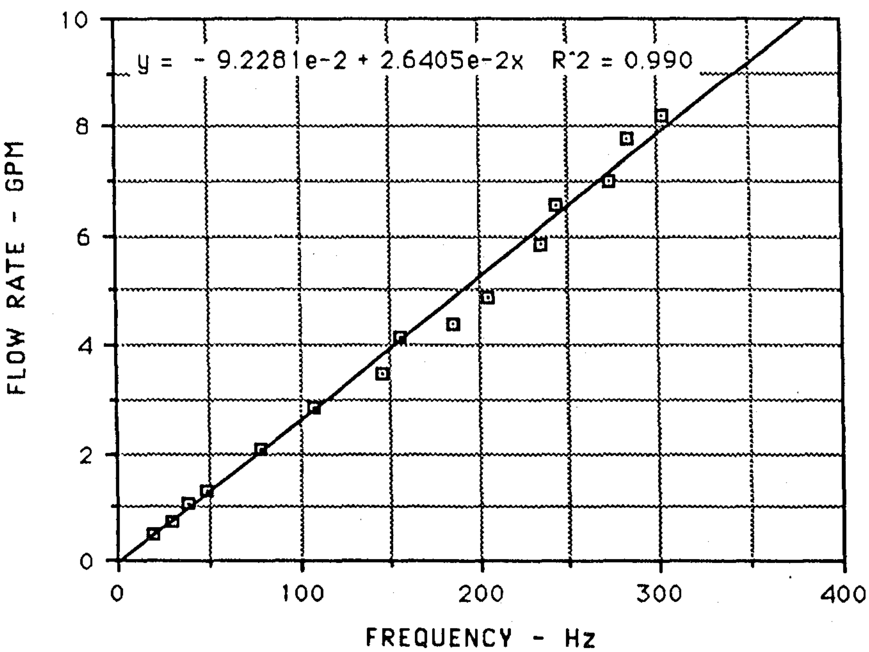

FIG. 3.7c 0.5" MODEL -REVERSED WEDGE BAR - FREON

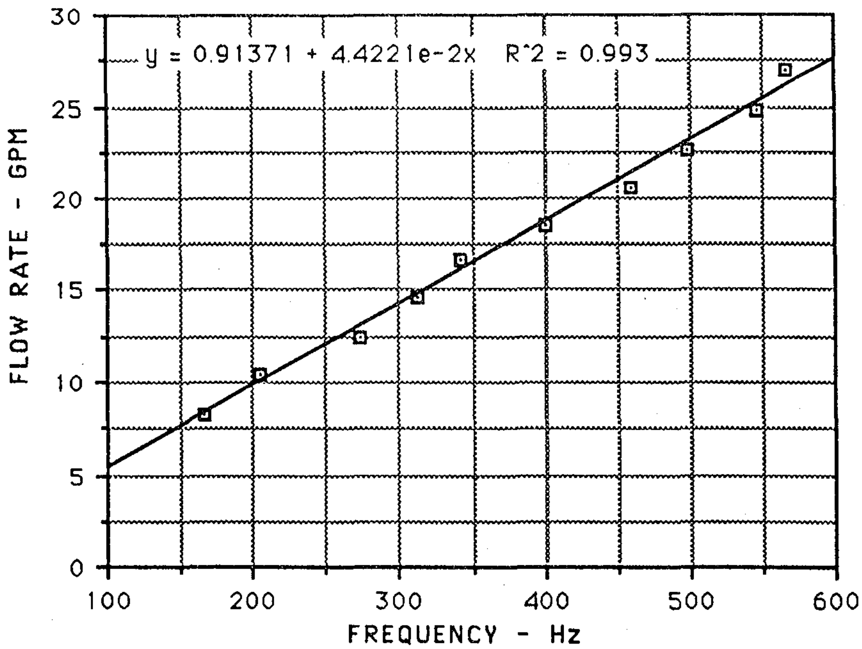

FIG. 3.8a .75" MODEL - RECT. BAR - WATER

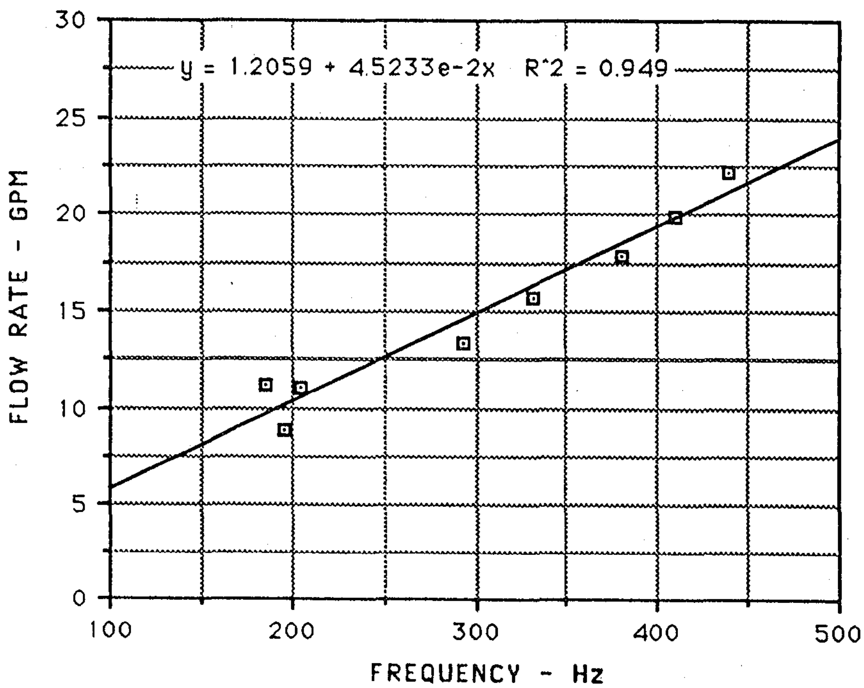

FIG. 3.8b .75" MODEL - CYL. BAR - WATER

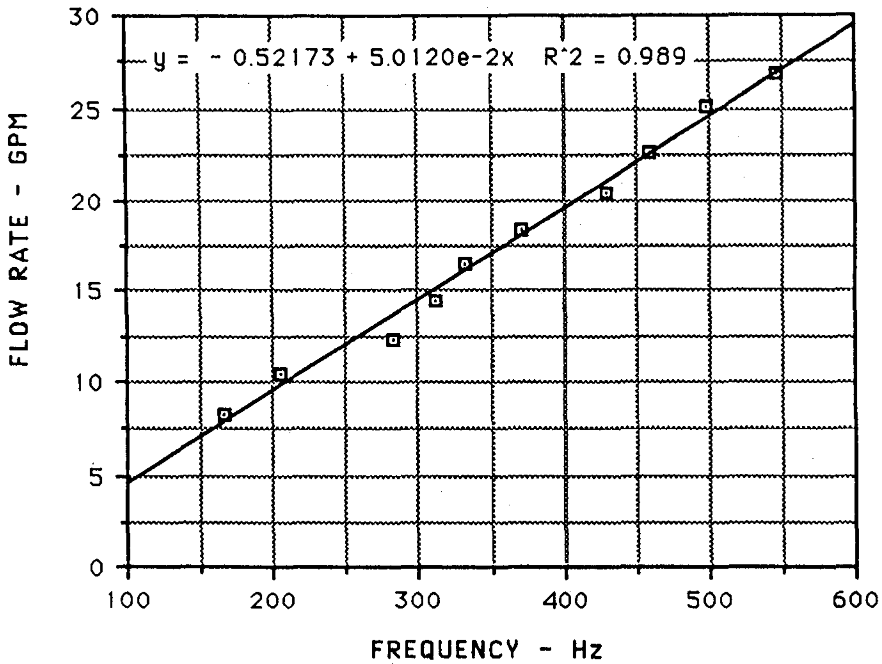

FIG. 3.8c .75" MODEL - REVERSED WEDGE BAR - WATER

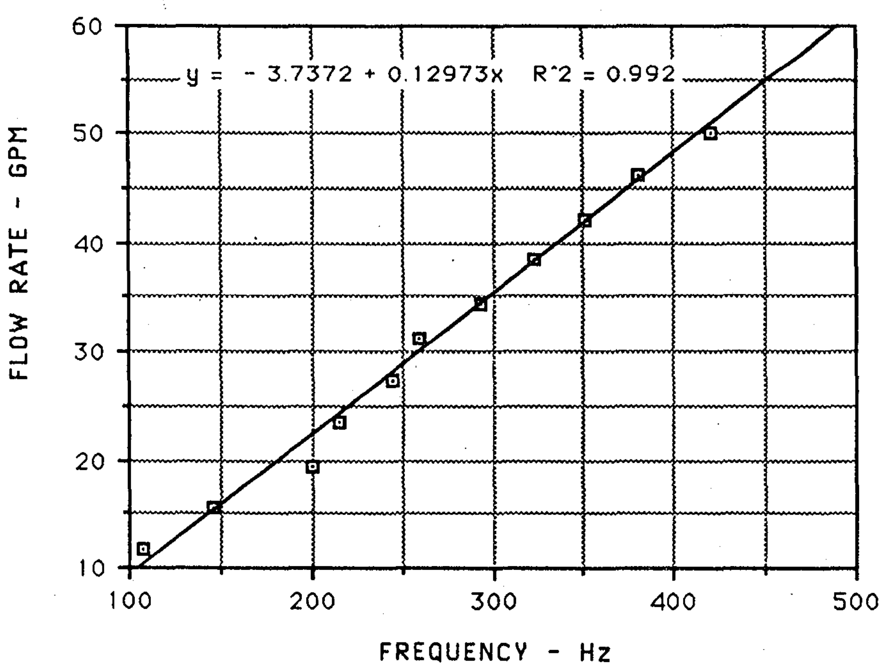

FIG. 3.9a 1" MODEL -RECT. BAR - WATER

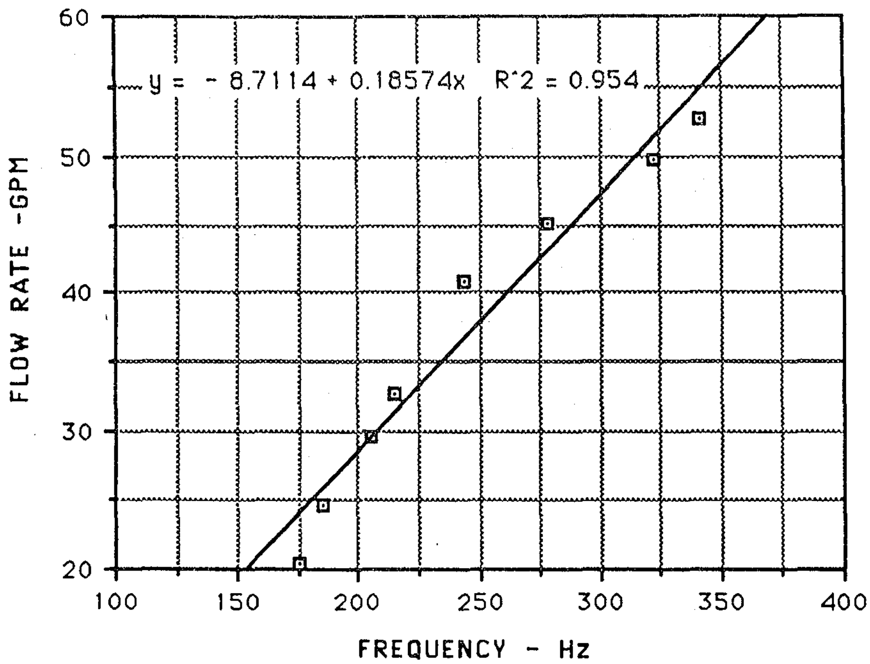

FIG. 3.9b 1" MODEL - CYL. BAR - WATER

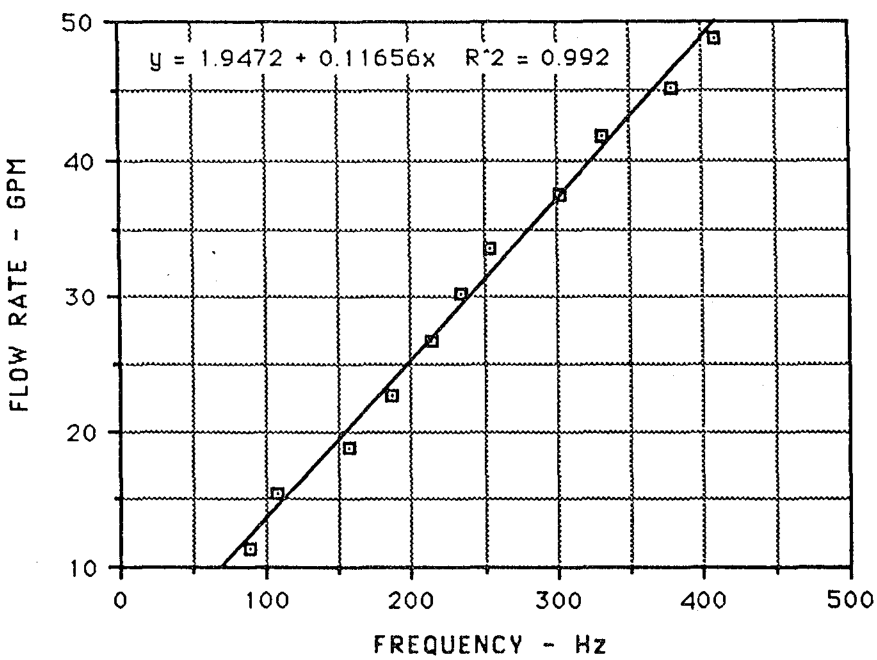

FIG. 3.9c 1" MODEL - REVERSED WEDGE BAR - WATER

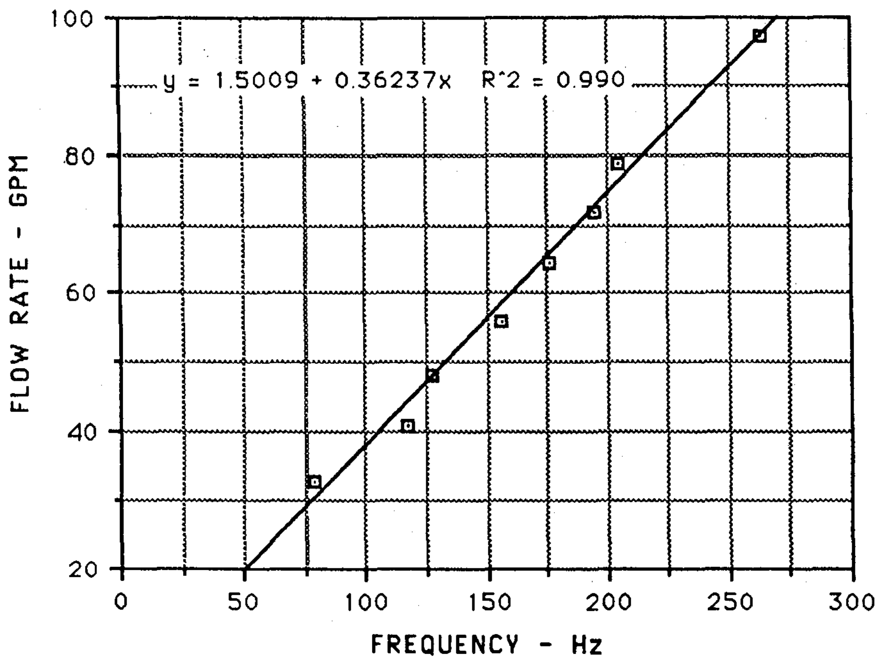

FIG. 3.10a 1.5" MODEL - RECT. BAR - WATER

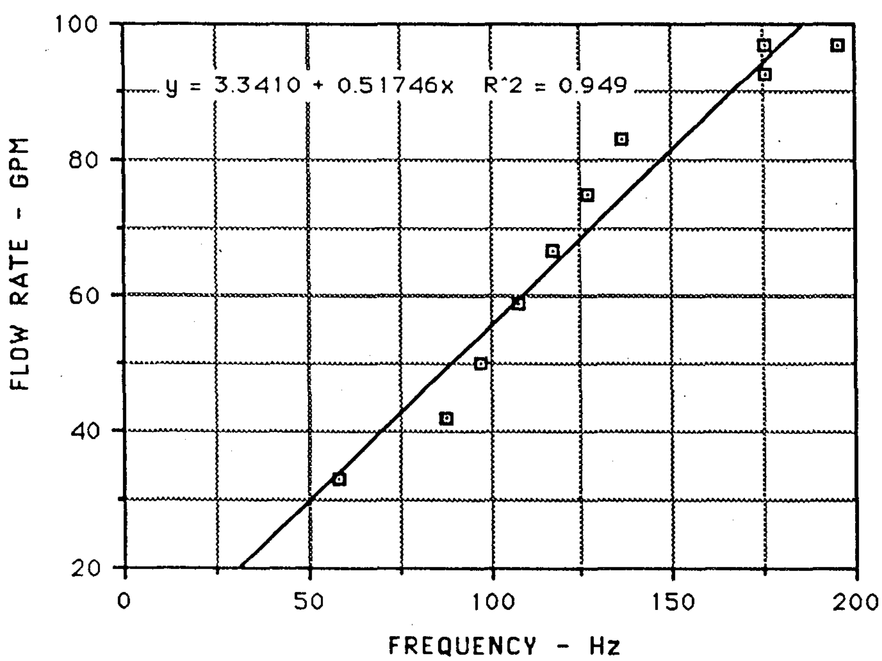

FIG. 3.10b 1.5" MODEL - CYL. BAR - WATER

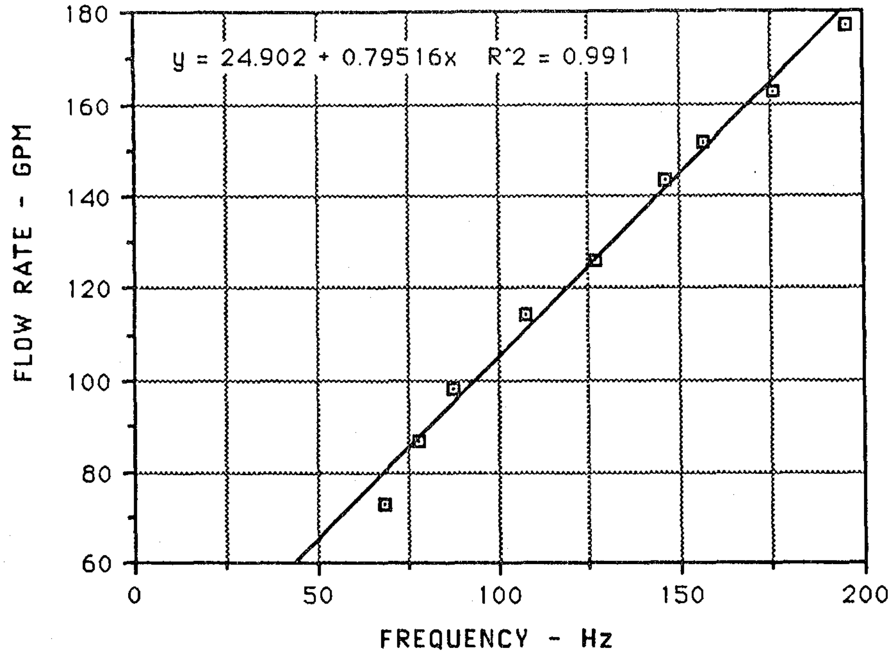

FIG. 3.11a 2" MODEL - RECT. BAR - WATER

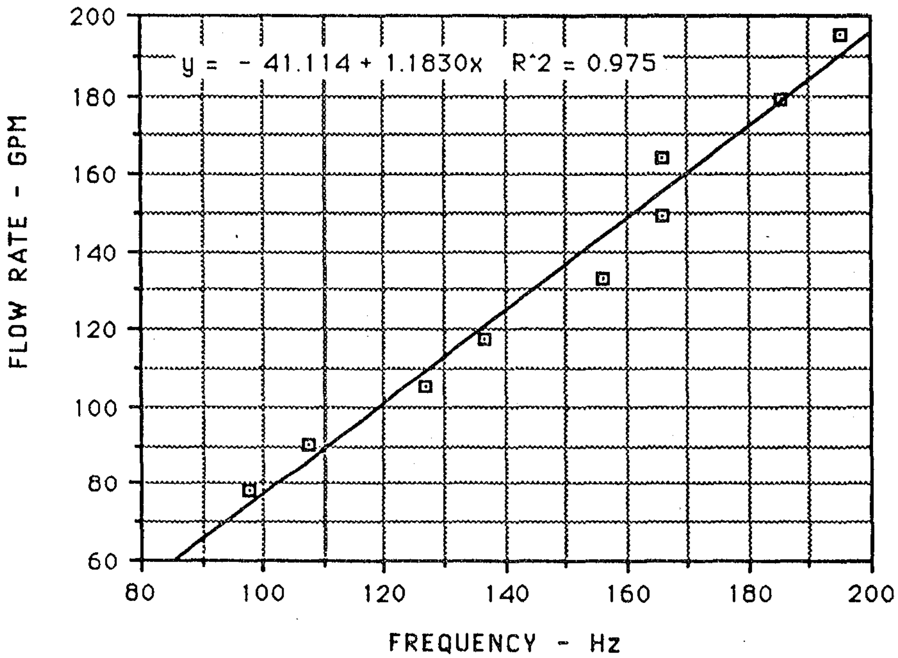

FIG. 3.11b 2" MODEL - CYL. BAR - WATER

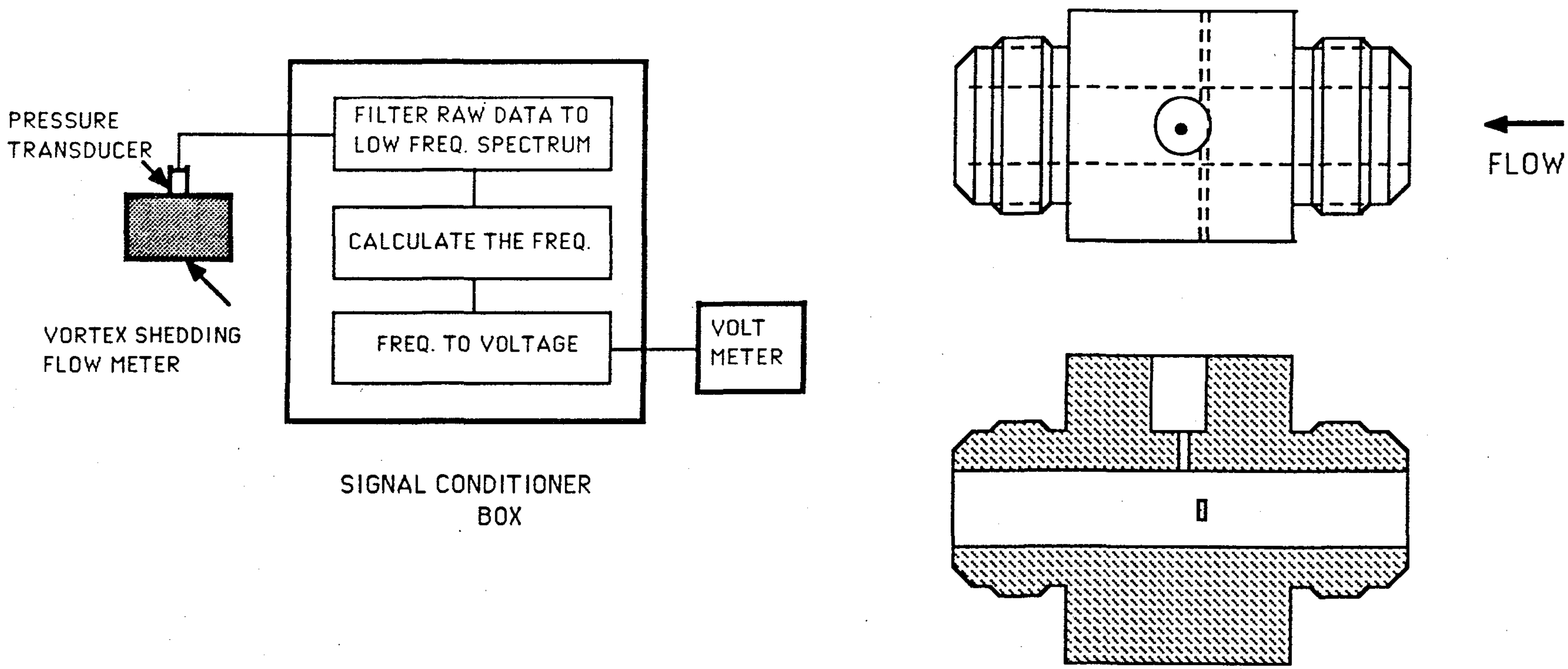

FIG. 3.12 PROTOTYPE FOR QUALIFICATION TEST AND SPEC. REQUIREMENTS